Carbohydrates: Structure & Function

Lecture 4

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Editing File

Biochemistry
442

Objectives

- To understand the structure of carbohydrates of physiological significance.
- To understand the main role of carbohydrates in providing and storing energy.
- To understand the structure and function of glycosaminoglycans.

Overview of Carbohydrates

Carbohydrates:

- They are the most abundant organic molecules in nature.
- The empirical formula for carbohydrates is **(CH2O)n**.
- They are also named: hydrates of carbon.

Functions of carbohydrates include:

- Provide important part of energy in our diet.
- Act as the storage form of energy in the body.
- Are structural component of cell membranes.

-n >= 3 (3 is the minimum)

-Glycogen in the liver

-Cell membrane components: proteins,carbohydrates, and phospholipids.

Overview of Carbohydrates

Many diseases are associated with disorders of carbohydrate metabolism including:

- **Diabetes Mellitus (DM)**
- **Galactosemia** (which means "galactose in the blood". When people with galactosemia ingest foods or liquids containing galactose, undigested sugars build up in the blood because the body's ability to process galactose is blocked)
- **Glycogen Storage Diseases** (the result of defects in the processing of glycogen synthesis or breakdown within muscles, liver, and other cell types)
- **Lactose Intolerance** (disorder caused by the inability to digest lactose, the main carbohydrate in dairy products)

Classification of Carbohydrates:

1

Monosaccharides

simple sugar

Ex: Glucose

2

Disaccharides

2 monosaccharides units

Ex: Lactose

3

Oligosaccharides

3-10 monosaccharide units

4

Polysaccharides

more than 10 monosaccharide units

- Heteropolysaccharides: monosaccharides are different
- Homopolysaccharides: monosaccharides are identical

Monosaccharides

Monosaccharides are further classified based on:

1- Number of carbon atoms

***Note:** not very important

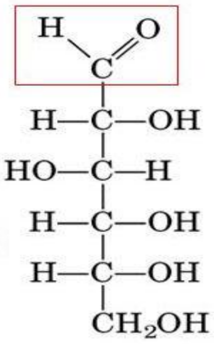
Generic Name	Example
3C: trioses	Glyceraldehyde
4C: tetroses	Erythrose
5C: pentoses	Ribose
6C: hexoses	Glucose
7C: heptoses	Sedoheptulose
9C: nonoses	Neuraminic acid

Monosaccharides

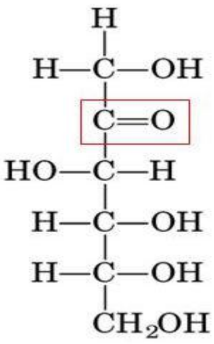
Monosaccharides are further classified based on:

2- Functional sugar group

- Aldehyde group – **aldoses**
- Keto group – **ketoses**



D-Glucose,
an aldohexose



D-Fructose,
a ketohexose

441 Note:

-Keto sugar: the carbonyl group is within the chain

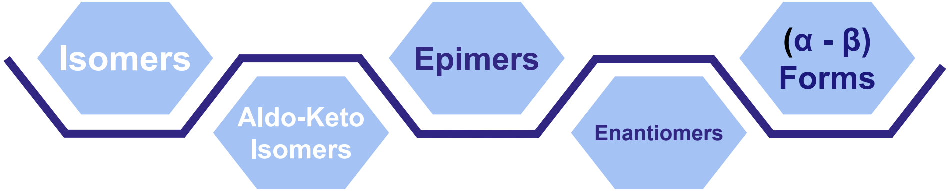
-Aldehyde sugar: the carbonyl group is at the end of the chain.

	Aldose	Ketose
Triose	Glyceraldehyde	Dihydroxyacetone
Pentose	Ribose	Ribulose
Hexose	Glucose	Fructose

Types of Isomerism:

- Isomers
- Aldo-Keto Isomers
- Epimers
- Enantiomers
- (α - β) Forms

Types of Isomerism:



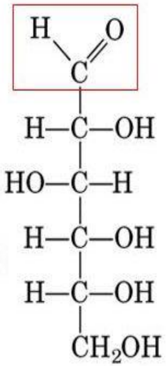
Isomers

- Isomer are compounds that have the same chemical formula but different structural formulas.

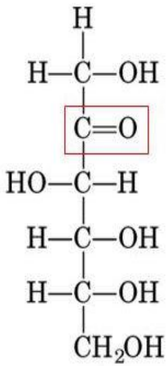
Aldo-Keto Isomers

- **Aldo-Keto Isomerism** is a type of isomerism, which happens when one compound is an Aldose (has Aldehyde as a functional group) and the other compound is a Ketose (has a Ketone as a functional group).

- **E.g**: Fructose (Ketose) and Glucose (Aldose) which are Aldo-Keto Isomers.



D-Glucose, an aldohexose



D-Fructose, a ketohexose

441Note: Fructose and Glucose both share the same chemical formula ($C_6H_{12}O_6$) but different structural formula.

Numbering: functional group gets smallest number when counting

Types of Isomerism:

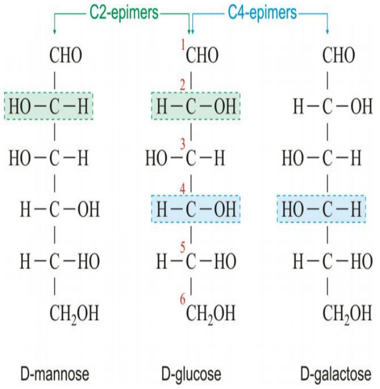
Isomers | Aldo-Keto Isomers | Epimers | Enantiomers | (α - β) Forms

Epimers

Epimers are CHO dimers that differ in configuration around **only one** specific carbon atom.

E.g:

- Glucose and Galactose, C4
- Glucose and Mannose, C2
- Galactose and Mannose are NOT epimers (because they differ in configuration around more than one carbon, so they are only isomers)



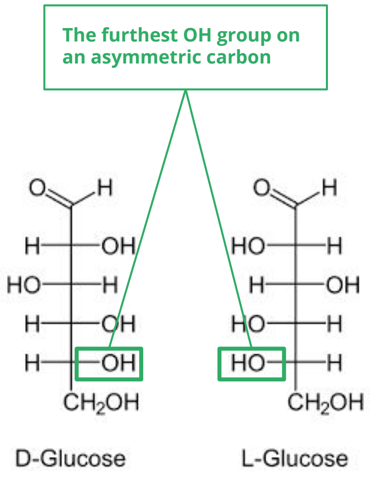
Isomers | Aldo-Keto Isomers | Epimers | Enantiomers | (α - β) Forms

Types of Isomerism:

Enantiomers (D- & L-Forms)

Enantiomers are structures that are **mirror images** of each other and are designated as **D-** and **L-** sugars, based on the position of -OH group on the **furthest asymmetric carbon** from the carbonyl carbon.

- Majority of sugars in humans are D-sugars.
- Most of amino acids in humans body are L-configuration.
- A carbon is **asymmetric** when it's attached to four different types of atoms or groups of atoms. Asymmetric carbons are **optically active.**



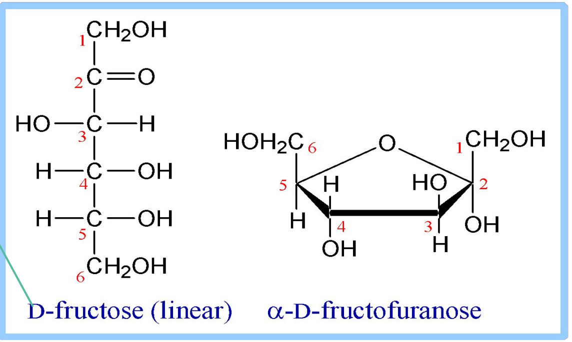
Isomers | Aldo-Keto Isomers | Epimers | Enantiomers | (α - β) Forms

Types of Isomerism:

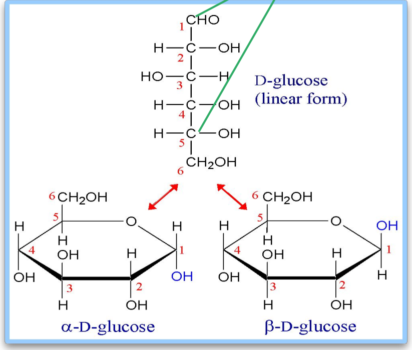
α & β configurations

- Cyclization of monosaccharides with 5 or more carbons are predominantly found in the ring form.
- The Aldehyde or Ketone group reacts with the -OH group on the same sugar.
- Cyclization creates an anomeric carbon (former carbonyl carbon) generating the α and β configurations.
- We add the configuration β when OH- is above, and we add α when OH- is below.
- The structure of these carbohydrates might show that they are an open chain, in fact most of the carbs with 5+ carbons are cyclic.

The furthest OH- group on an asymmetric carbon on the RIGHT SIDE



Ring attachment

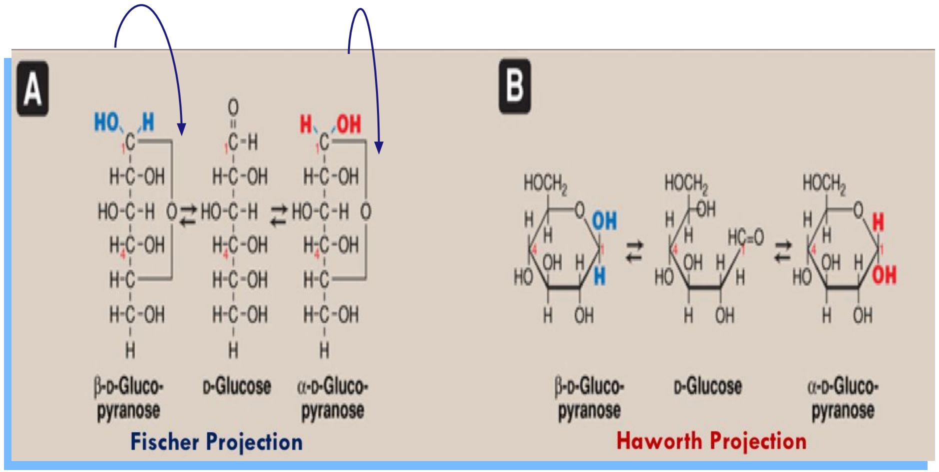


- Anomeric Carbon gives 2 forms: **α - β configurations**
- **Aldose: anomeric carbon is C1** (interacts with C5)
- **Ketose: anomeric carbon is C2** (interacts with C5)

Mutarotation

In a solution, the cyclic α and β anomers of a sugar are in equilibrium with each other, and can be interconverted spontaneously.

439Note: Sugar in its normal condition is always in a ring form (Haworth projection) but when the sugar is put in water, the ring is separated and becomes a linear form (Fischer projection) so the -OH location changes and isn't stable.



441Note: In Fischer Projection: We add the **α** configuration when the OH group is near the O atom, and the **β** group when the OH group is far from the O atom. (Look at the arrows).

***Note:** Fischer Projection resembles a fish skeleton :).

[Helpful Video :)]

Disaccharides

Definition: It is the joining of 2 monosaccharides by O-glycosidic bond.

An oxygen is always shared

Examples:

Maltose

(α-1, 4) =
glucose + glucose

Sucrose

"Table sugar"

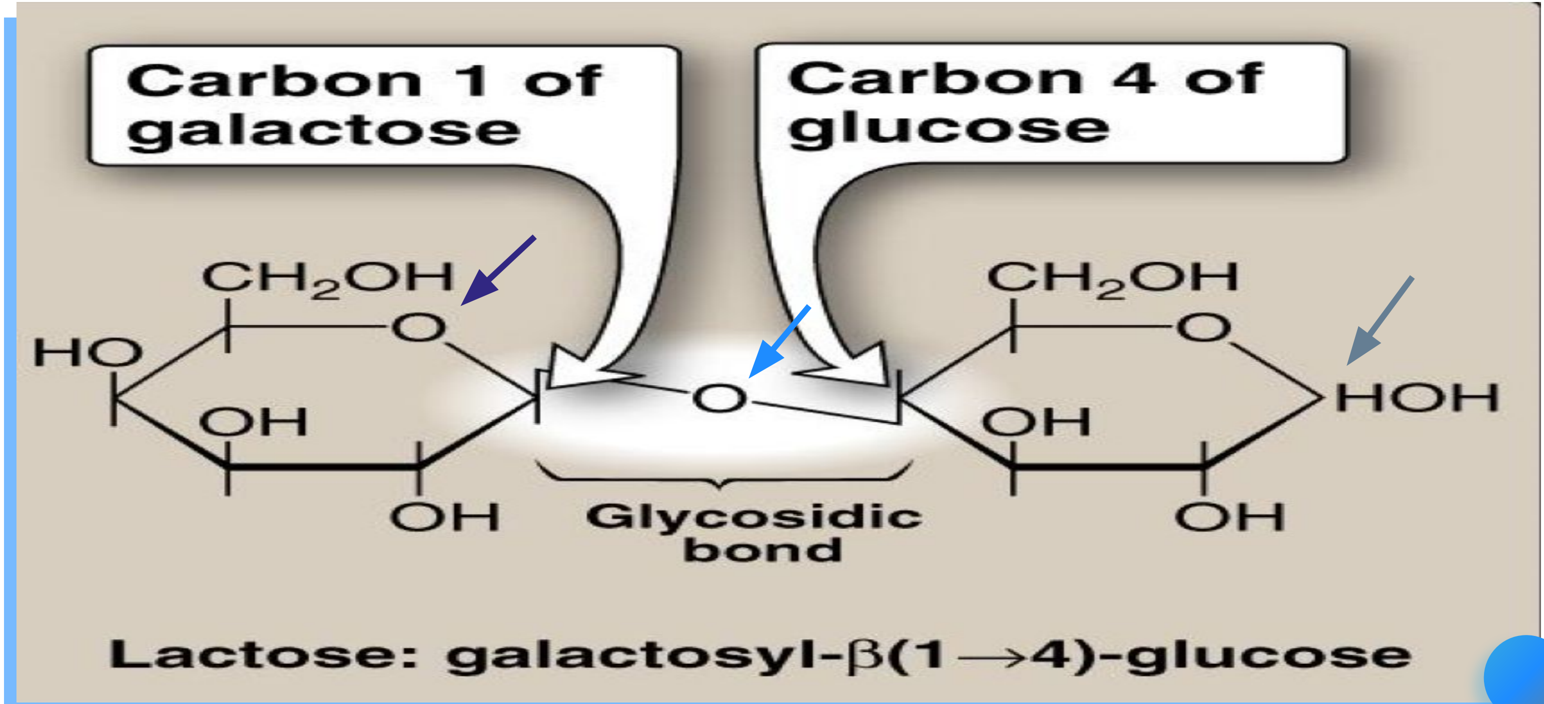
(α-1,2) =
glucose + fructose

Lactose

(β-1,4) =
galactose + glucose

Helpful Video :)

Lactose



carbon next to the oxygen is anomeric oxygen taken from galactose free anomeric C= reducing sugar

Reducing Sugar

- **Free anomeric carbon + reducing agent = reducing sugar**

- If the O on the anomeric C of a sugar is not attached to any other structure (**free**), that sugar can act as a reducing agent
- Reducing sugars reduce chromogenic agents like Benedict's reagent or Fehling's solution to give a colored precipitate
- Urine is tested for the presence of reducing sugars using these colorimetric tests

Examples:

1-Monosaccharides
2-Maltose
3-Lactose

Sucrose is non-reducing, Why? sucrose is the combination of Glucose and Fructose (each of them combine with the other in the carbonyl group) and therefore none of them have a free aldehyde or ketone group (the anomeric C is attached). In other words the anomeric carbon is busy. **439Note**

Helpful Video :)

Polysaccharides

Homopolysaccharides

same type of simple sugars (all monomers units are the same)

- **Branched:**
  Glycogen and starch
  E.g: (amylopectin)
  (α-glycosidic polymer)
- **Unbranched:**
  Cellulose
  (β-glycosidic polymer)

Heteropolysaccharides

different types of simple sugars (contain two or more different monosaccharide units)

- E.g: glycosaminoglycans (GAGs)

439Note: Glycogen, Starch, and Cellulose are all made of glucose

[**Helpful Video**](#) :)

Complex Carbohydrates

Carbohydrates attached to non-carbohydrate structures by glycosidic bonds **(O- or N-type)**.

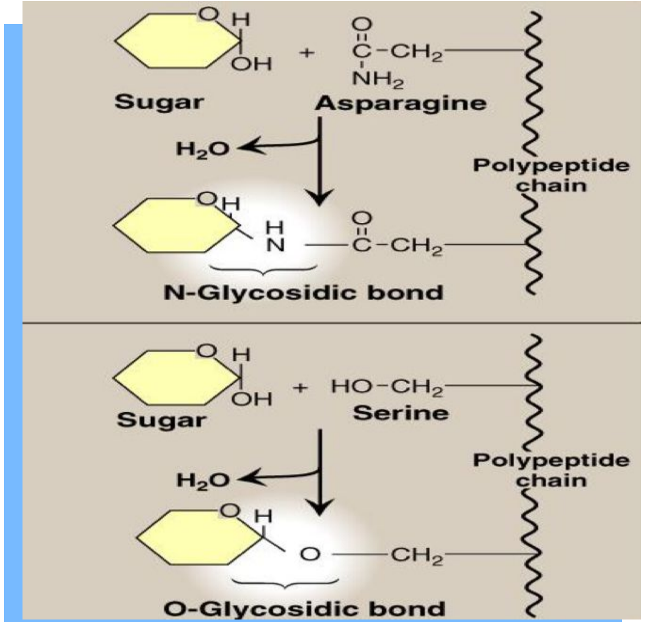
Examples:

1. **Purine and pyrimidine bases** in nucleic acids
2. **Bilirubin** (product of hemoglobin)
3. **Proteins** in glycoproteins and proteoglycans
   Note441: Glycoproteins are proteins covalently bonded with carbohydrates (majority protein).
   Proteoglycans are a subclass of glycoproteins in which the carbohydrate units are polysaccharides that contain amino sugars. (majority carbohydrates).
4. **Lipids** found in glycolipids
   Glycolipids are basically lipids the have some sugar molecules attached to them **(441).**

Complex Carbohydrates

N-Glycosidic: Attachment happens at **N** atom. **Asparagine** is famous for forming this type of bond.

O-Glycosidic: Attachment happens at **O** atom. **Serine** is famous for forming this type of bond.



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Glycosaminoglycans (GAGs)

- Glycosaminoglycans (GAGs) are large complexes of **negatively** charged **hetero**polysaccharide chains
- They are associated with a small amount of protein, forming proteoglycans, which consist of over 95% carbohydrates.
- They bind with large amounts of water, producing the gel-like matrix that forms the body's ground substance. Ground substance is the non-fibrous protein of our extracellular matrix (stuff outside the cells of our bodies) in which the other components are held in place.
- GAGs are linear polymers of repeating disaccharide units: **(acidic sugar-amino sugar)n**

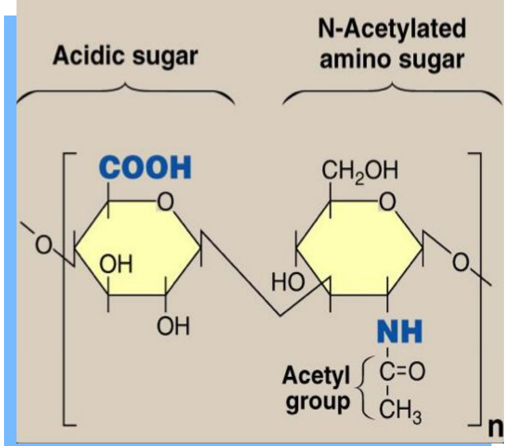
The acidic sugar is either: D-glucuronic acid or L-iduronic acid

The amino sugar (usually sulfated) is either: D-glucosamine or D-galactosamine

Helpful Video :)

Glycosaminoglycans (GAGs) Cont

• The viscous(لزج),lubricating(تشحيم\تزييت) properties and mucous (مخاط)secretions also result from GAGs, which led to the original naming of these compounds as Mucopolysaccharides.



GAGs are strongly negatively charged because of:

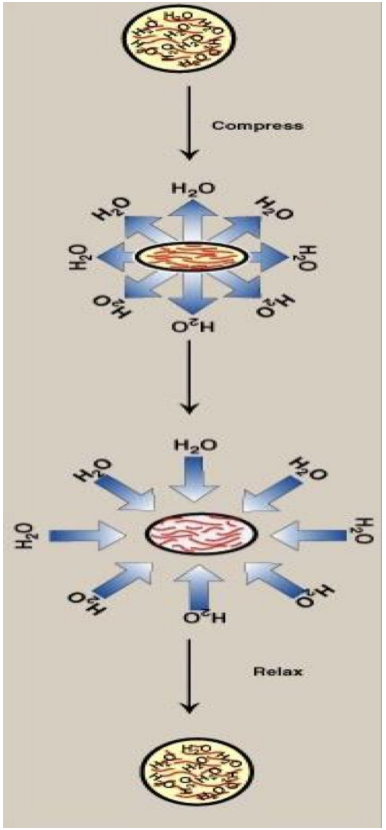
• The carboxyl group of the acidic sugar
• The sulfate group
• NH (+) is occupied with the Acetyl group **(441)**

Resilience of GAGs

Relationship between glycosaminoglycan structure and function:

- Because of negative charges, the GAG chains tend to be extended in the solution and repel each other, and when brought together, they "slip" past each other. This produces the "slippery" consistency of mucous secretions and synovial fluid.
- When a solution of GAGs is compressed, the water is "squeezed out" and the GAGs are forced to occupy a smaller volume.
- When the compression is released, the GAGs spring back to their original, hydrated volume because of the repulsion (تنافر) of their negative charges.
- This property contributes to the resilience (صمود\مناعة) of synovial fluid and the vitreous humor of the eye.

الـsynovial fluid هو سائل يتواجد بين المفاصل ويمنع الاحتكاك اما ال vitreous humor هو سائل يتواجد داخل العين (439TEAM)



Examples of GAGs are:

- Chondroitin sulfates: Most abundant GAG, found in the bones and cartilage.
- Keratan sulfates: Most heterogeneous GAG that exists, It is found in the cornea of the eye.
- Hyaluronic acid: Compared to other GAGs, it is the only one that is unsulfated and not covalently attached to protein.
- Heparin: Unlike other GAGs, that are extracellular, heparin is **intracellular** and serves as an (مضاد تخثر) anticoagulant.

Take Home Messages

- Structure and function of carbohydrates.
- Mono-, Di-, and Polysaccharides.
- Sugar Isomers: Aldo-keto, epimers, D- and L-, α-and β-anomers.
- Complex carbohydrates: E.g. Glycosaminoglycans and Proteoglycans.
- Structure and function of GAGs.
- Examples of GAGs: chondroitin sulfate, keratin sulfate, hyaluronic acid and heparin

Quiz

1- An example of pentose (ketose) is:			
a) Ribose	b) Fructose	c) Ribulose	d) Glucose
2- The number of the anomeric carbon in Fructose is:			
a) C2	b) C3	c) C4	d) C5
3-Sucrose is a non-reducing sugar because:			
a) it has alpha glycosidic polymers	b) it has beta glycosidic polymers	c) it has hetero-polysaccharides	d) it is attached head to head at anomeric carbons
4- Large complexes of negatively charged heteropolysaccharide chains are:			
a) Glycosaminoglycans	b) Haworth projection	c) Fischer projection	d) Monosaccharides
3-Which one is not attached to any complex carbohydrates:			
a) Bilirubin	b) Proteins	c) Lipids	d) Oxygen (O2)

1. C
2. A
3. D
4. A
5. D

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